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Emissions of Naturally Occurring Radioactivity Stauffer Elemental Phosphorus Plant

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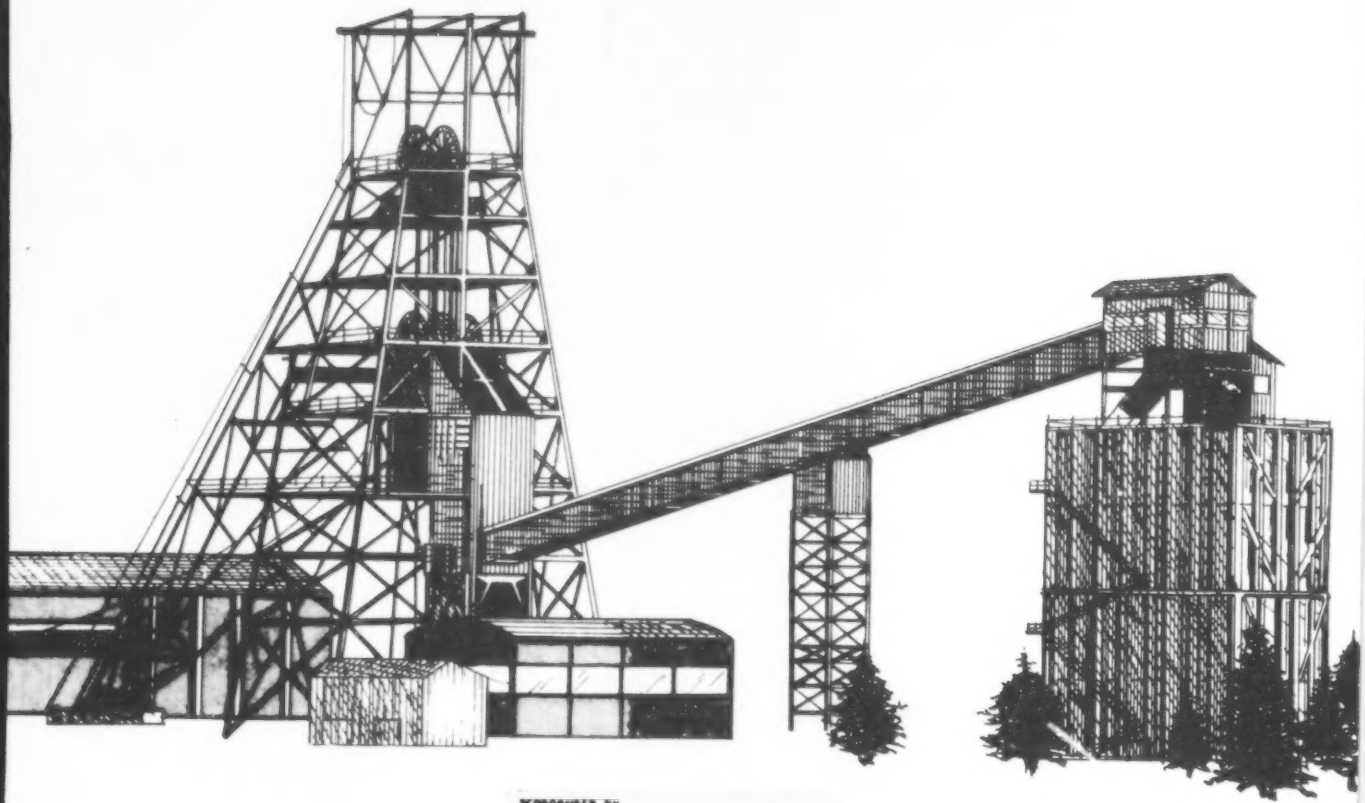

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16. ABSTRACT

Naturally occurring radioactivity was measured in the atmospheric emissions and process materials of a thermal phosphate (elemental phosphorus) plant. Representative exhaust stack samples were collected from each process in the plant. The phosphate ore contained about 120 parts per million uranium. The radioactivity emitted in greatest quantity was radon-222 with an annual release from the plant of 8.3 curies. Emissions of lead-210 and polonium-210 were measured at 280 and 200 millicuries per year. Annual emissions of each of the other radionuclides of the uranium decay chain were estimated to be 4.2 millicuries. The slag pile was determined not to be a source of radon.

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DISCLAIMER

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FORWARD

The Office of Radiation Programs (ORP) of the U.S. Environmental Protection Agency (EPA) conducts a national program for evaluating exposure of humans to ionizing and nonionizing radiation. The goal of this program is to develop and promote protective controls necessary to ensure the public health and safety.

In response to the 1977 amendments to the Clean Air Act the Las Vegas Facility was given the responsibility to collect field data on emissions to the atmosphere of natural radioactivity from operations involved in the mining, milling, and smelting of minerals other than uranium and coal. This report is one of a series which describes an individual facility and the associated radioactivity emissions.

ORP encourages readers of the report to inform the Director, ORP-Las Vegas Facility, of any omissions or errors. Comments or requests for further information are also invited.

Wayne A. Bliss, Acting Director
Office of Radiation Programs
Las Vegas Facility

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SECTION 1

BACKGROUND

The Clean Air Act, as amended in August 1977, required the Administrator of the Environmental Protection Agency (EPA) to determine whether emissions of radionuclides into ambient air should be regulated under the Act. In December 1979 the Administrator listed radionuclides as a hazardous pollutant under Section 112 of the Clean Air Act.

The naturally occurring radionuclides most likely to be emitted in significant quantities are those in the uranium-238 and thorium-232 decay series (Figure 1). These radionuclides and their daughter products occur naturally in widely varying amounts in the soils and rocks that make up the earth's crust. Average values for uranium-238 and thorium-232 in soils are approximately 1.8 ppm (0.6 pCi/g) and 9 ppm (1 pCi/g) respectively (1). The radioactivity concentration of each of the daughter products in the two series is approximately equal to that of the uranium-238 or thorium-232 parent.

Almost all operations involving removal and processing of soils and rocks release some of these radionuclides into the air. These releases become potentially important when the materials being handled contain above-average radionuclide concentrations or when processing concentrates the radionuclides significantly above the average amounts in soils and rocks.

Because mining and milling operations involve large quantities of ore, and because there is little information about how these activities release radioactive emissions, EPA, in 1978, began to measure airborne radioactive emissions from various mining, milling, and smelting operations. These surveys were screening studies designed to identify important sources of airborne emissions of radionuclides at individual facilities.

Operations were selected for study on the basis of their potential to emit significant quantities of naturally occurring radionuclides to the atmosphere. Some of the factors in the selection included typical mine size, annual U.S. production, measured working levels of radon daughters in underground mines and associated ventilation rates, production rate and process of individual facilities, and previous association with naturally occurring radionuclides. Usually, we chose to look at large facilities in order to improve the chances of obtaining emission samples with radioactivity contents significantly greater than background.

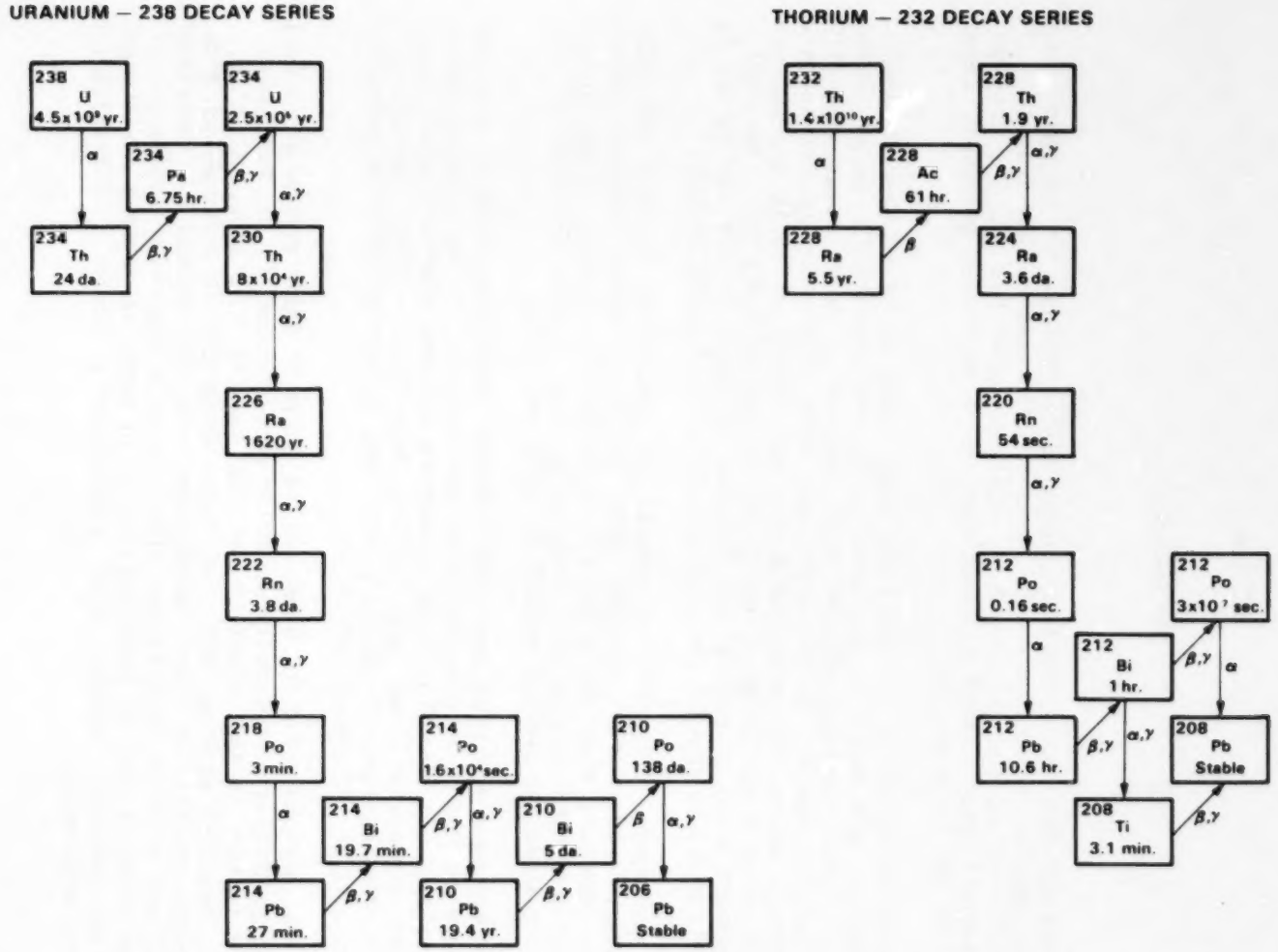

Figure 1. Uranium and Thorium Radioactivity Decay Schemes

SECTION 2

INTRODUCTION

As early as 1908 it was recognized that phosphate rock contained above-normal concentrations of uranium and thorium (2). Those concentrations have been observed in the United States to range from 8 to 399 ppm (2.7 to 133 pCi/g) of uranium-238 and 2 to 19 ppm (0.22 to 2.1 pCi/g) of thorium-232 (3). South Carolina ores had the highest concentrations, while the lowest were found in Tennessee. During the 1950's uranium was recovered as a byproduct of phosphate production.

Since 1974 the EPA has studied various aspects of the radioactivity released to plant environs during benefication and processing of the phosphate ores. The EPA had conducted a comprehensive radiological survey of a thermal phosphate (elemental phosphorus) plant in 1975 (4). However, problems associated with the analyses for lead-210 had greatly reduced the accuracy of the measurements of both lead-210 and polonium-210. Under the added emphasis provided by the Clean Air Act Amendments the decision was made to include at least two elemental phosphorus plants in this series of surveys. The first of the plants surveyed was the Stauffer Chemical Company plant in Silver Bow, Montana.

PEDCo Environmental, under contract with EPA, conducted the survey and collected samples (5). Before the survey, representatives of PEDCo Environmental and EPA visited the plant to select sampling locations. During the period October 15-31, 1979 PEDCo Environmental, accompanied by an EPA representative, conducted the sampling and measurement program, collecting particulate and gas samples from plant effluents and ambient air as well as information on plant operations. Stauffer provided meteorological data collected by one of their meteorology stations.

SECTION 3

SUMMARY

PEDCo Environmental collected samples of particulate and gaseous emissions from all controlled sources at the Stauffer Chemical Company plant. Ambient particulate and gaseous samples were collected at a site 1.6 km east of the plant. Radon-222 emanation rates were measured from soil around the plant, from an ore storage pile, and the slag pile.

The kiln stacks emitted essentially all of the radioactivity emitted from controlled sources. They accounted for 99 percent of the lead-210, 97 percent of the polonium-210, and 98 percent of the radon-222. Annual emission rates of the three radionuclides from all stacks were measured at 280 mCi for lead-210, 200 mCi for polonium-210, and 8.2 Ci for radon-222. An additional estimated release of 1.2 Ci/y of radon-222 is produced by ore in storage. Annual emission rates of uranium-238 and -234, thorium-230, and radium-226 were measured at an average amount of 0.22 mCi for each radionuclide. The estimated release of each of those radionuclides, based on measured mass emission rates and assuming that the radioactivity concentration in the emitted particulates was the same as in the materials handled by the process was 4.2 mCi/year.

The radon emanation rate from the slag pile, with an average radium-226 concentration of 27 pCi/g was 3.5 ± 3.7 pCi/m^2-min; much less than the soil emanation rate of 18 ± 9 pCi/m^2-min. The average emanation rate from the ore pile was 117 ± 138 pCi/m^2-min.

SECTION 4

PLANT OPERATIONS

PRODUCT FLOW

The Stauffer Chemical Company Silver Bow Plant is located in the community of Silver Bow, approximately 11 km west of Butte, Montana (Figure 2). Ore is delivered by rail from a mine in Idaho. The plant product is elemental phosphorus. A by-product is ferrophosphorus (FeP), which is sold as a steel alloying additive. The other solid product is slag, which can be either a by-product or a waste product. Stauffer sold their slag for use as highway aggregate until shortly before this survey. Pending further radiation studies, Stauffer voluntarily withdrew their slag from the market.

Figure 3 is a schematic of the plant operation. Ore railcars are dumped into a pit from which ore is moved to one of two large storage piles (Figure 4). The process of ore blending begins at this point as the ore stockpile is built up by layers. One pile is built while ore is drawn from the other pile. Because of the severe winter weather, ore is shipped during the summer and stockpiled for year-round use.

The ore is further blended when it is recovered from the stockpile and moved into a pit where it is transferred by hoppers in the kiln feed building.

It is necessary to form the finely divided ore into larger, stable agglomerates for proper operation of the reduction furnaces. This is accomplished by passing the ore through two rotary kilns at about 1300°C. The temperature of the ore is raised to its incipient melting point and the tumbling action forms the ore into the desired nodular form. The hot nodules pass through coolers and crushers before being conveyed to storage silos.

The furnace feed consists of a mix of ore nodules, silica rock, and coke. A proper fraction of silica is required to form slag with the necessary flow properties to facilitate removal from the furnace. The content of silica occurring naturally in the ore must be augmented with added silica. Coke is added as a carbon source to reduce the calcium phosphate ore to elemental phosphorus. The approximate reaction is:

$$2Ca_3(PO_4)2 + 10\ C + 6\ SiO_2 \longrightarrow P_4 + 10\ CO + 6\ CaSiO_3$$

Nodules, coke, and silica are fed from storage silos by means of a proportioning belt and skip hoist to "burden bins" which provide a continuous feed to the furnaces.

Feed material enters the electric arc furnaces from the top and progresses downward until reaching the molten layer on the bottom. Phosphorus and CO are

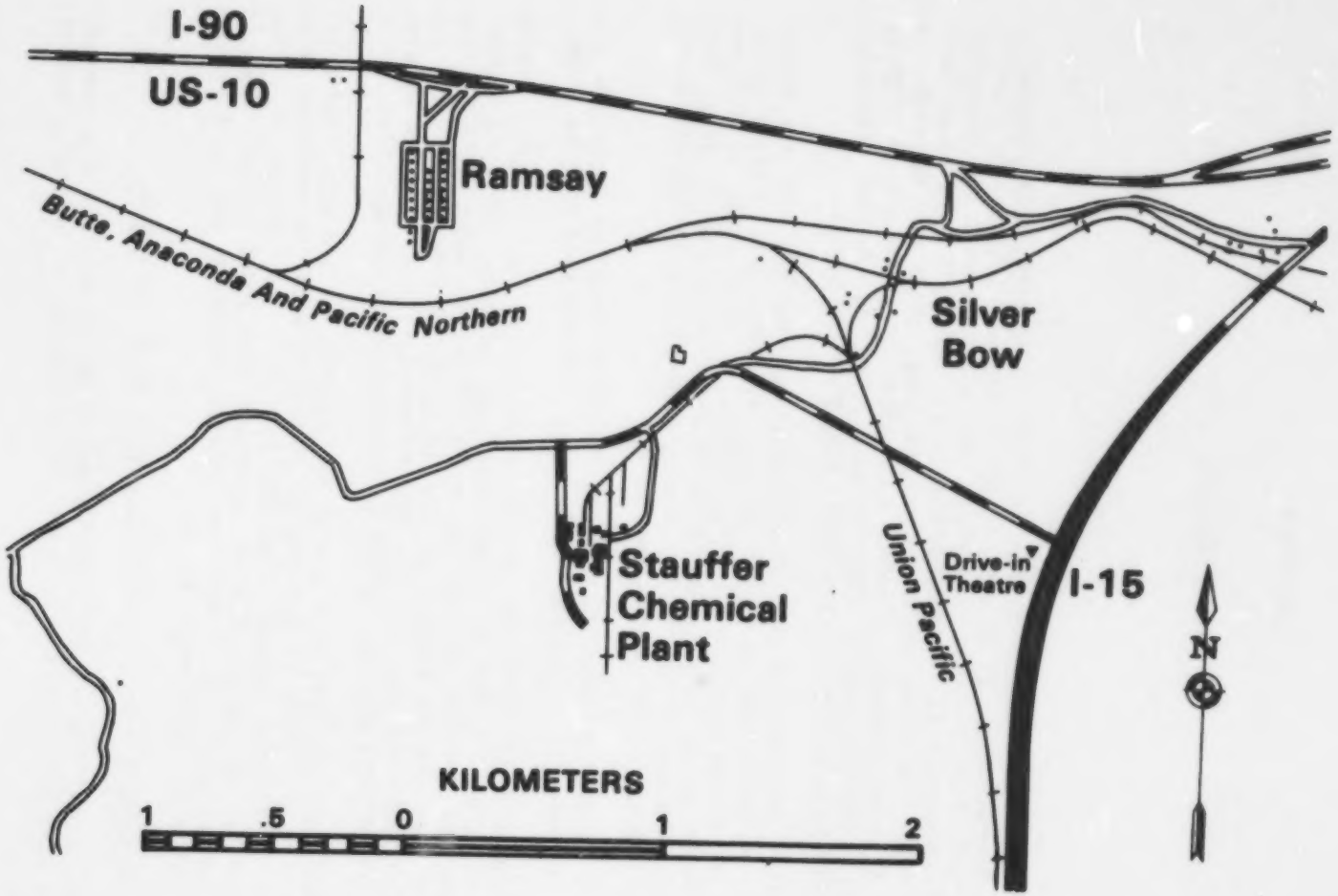

Figure 2. Stauffer Chemical Plant Location

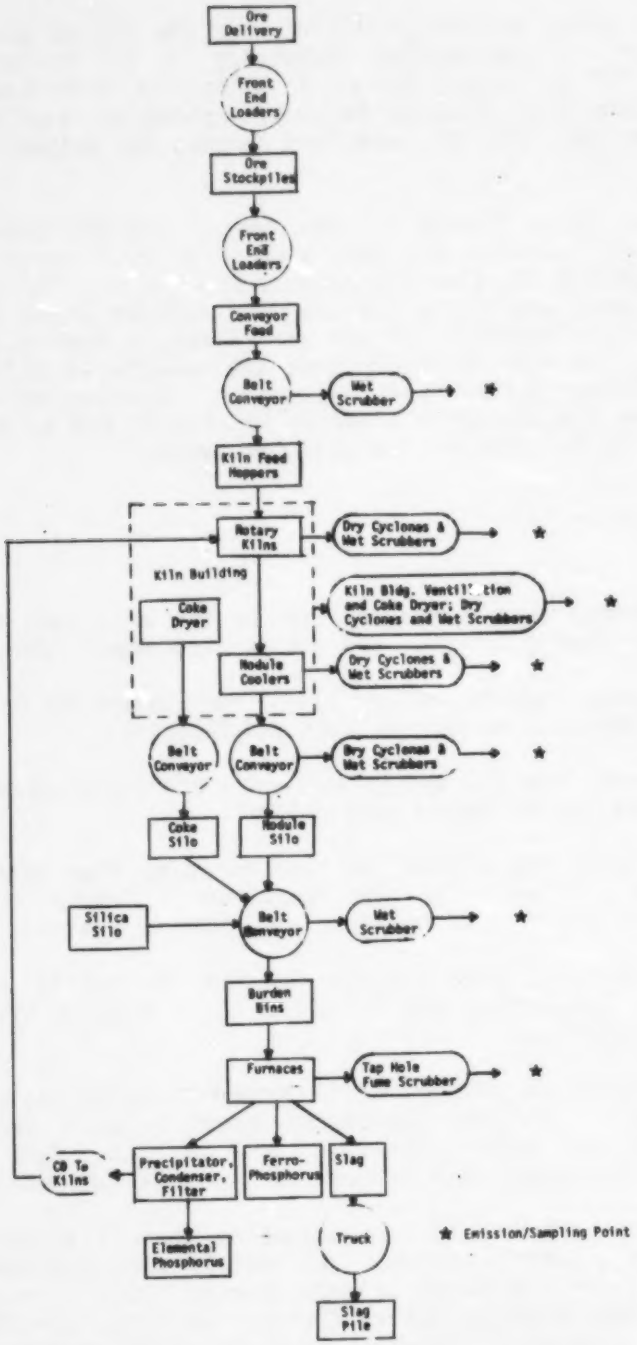

Figure 3. Stauffer Chemical Plant Flow Diagram

driven off as gases and are piped off near the top of the furnace. The slag and FeP which are continually collecting in the furnace are periodically tapped off. FeP is tapped for about 20 minutes each 8-hour shift. Slag is tapped (or flushed) in an 80 to 90 minute operation about seven or eight times per 24-hour period. FeP is cooled and crushed for shipment. Slag is disposed of on site.

The product gases through an electrostatic precipitator where particulate contaminants are removed, and then through a spray tower where water sprays cool the phosphorus to below the condensation point. The molten phosphorus is filtered to remove any carry-over particulates and piped into rail tank cars for shipment. The remainder of the gas stream, primarily CO, is used as fuel in the kilns. Sludge resulting from the phosphorus filtering operation is roasted to recover any residual phosphorus. Roaster residue is spread in a 6-inch layer on the stockpile prepared for winter use to prevent the damp ore from freezing in the pile and hampering recovery.

EMISSION POINTS

Dust generated while conveying ore to the kiln feed building hoppers is collected by a hooding system. The air is discharged through a wet scrubber.

Exhaust gases from the rotary kilns are cleaned by multiple air cleaning devices which remove both particulates and fluorine.

Exhaust gases from the nodule coolers are treated by two sets of multiple air cleaning devices to remove particulates.

Emissions occurring within the kiln building from materials handling and coke drying are collected by the ventilator collector system. This system exhausts through two sets of multiple air cleaning devices.

Emissions arising from transfer to and storage in the burden bins of nodules, coke, and silica are collected by a hooding system and discharged through a wet scrubber.

A small amount of phosphorus is released during slag and FeP tapping. Upon oxidizing in air the phosphorus forms a dense white cloud of P_2O_5 fumes. Collecting hoods intercept most of the P_2O_5 fumes and other emissions and discharges them through the tap hole fume scrubber.

With the installation of air pollution control systems on most of the sources of particulate emissions, the visible emissions during the period of the survey originated from two primary sources. One is a periodic release of some of the fumes produced during furnace tapping. The other source is the nodule storage silo area. Material handling at the burden bins generates considerable dust which exits the building through roof ridgeline ventilators. No satisfactory method has been devised to control these dust emissons. The point of emission is also inaccessible to sampling.

Other potential sources of airborne radioactivity were the ore storage piles and slag piles. These were considered as possible sources of gaseous radon-222.

SECTION 5

SAMPLE COLLECTION AND ANALYSIS

SAMPLE COLLECTION

Most samples were collected using EPA reference methods (6). Stack sampling points were selected according to EPA Method 1. Stack gas velocity and volumetric flow rate were determined by EPA Method 2. Gas samples for radon analysis were collected using EPA Method 3. (Radon in this report means radon-222). Total suspended particulates (TSP) in ducts and exhaust stacks were determined using EPA Method 5. High volume ambient TSP samples were collected in accordance with the Reference Method for the Determination of Suspended Particulates in the Atmosphere (7).

PEDCo collected Method 5 TSP samples on 7.6-cm (3-inch) diameter glass fiber filters. Ambient TSP samples were collected on 20.3- by 25.4-cm (8- by 10-inch) Microsorban polystyrene fiber filters. Stack gas and ambient whole air samples for radon analysis were collected in 30 liter Tedlar bags.

PEDCo sampled each of the emission points described on page 8 except the silo fugitive emissions. They collected two to four samples each of TSP and gas samples from each point. These points are shown in Figure 3. Where more than one exhaust of a given type existed, such as kiln exhausts, they only sampled one. At two locations it was possible to obtain simultaneous samples from the inlet and outlet of an emission control system.

Radon emanation rates from the surface of the ore pile and surrounding soil areas was measured at the locations shown in Figure 4 by means of charcoal canisters. U.S. Army M-11 gas canisters containing activated charcoal were placed on the surface to collect radon gas emitted. The canisters were left in position for the duration of the survey. Radon emanation rates from the slag pile were measured using inverted tubs sealed to the surface (Figure 4). The tubs were sealed to the slag pile using dry bentonite clay powder moistened in place. A valve and gas cock in the bottom of the tub permitted the collection of air samples at the time of placement and after an elapsed time of 2 to 3 hours. The change of radon concentration in the 53-liter tub made it possible to calculate the rate of emanation from the surface beneath the tub.

Samples of process materials were collected to relate radionuclide emission rates to the radioactivity of the material handled at each emission point and to permit a radionuclide balance through the process.

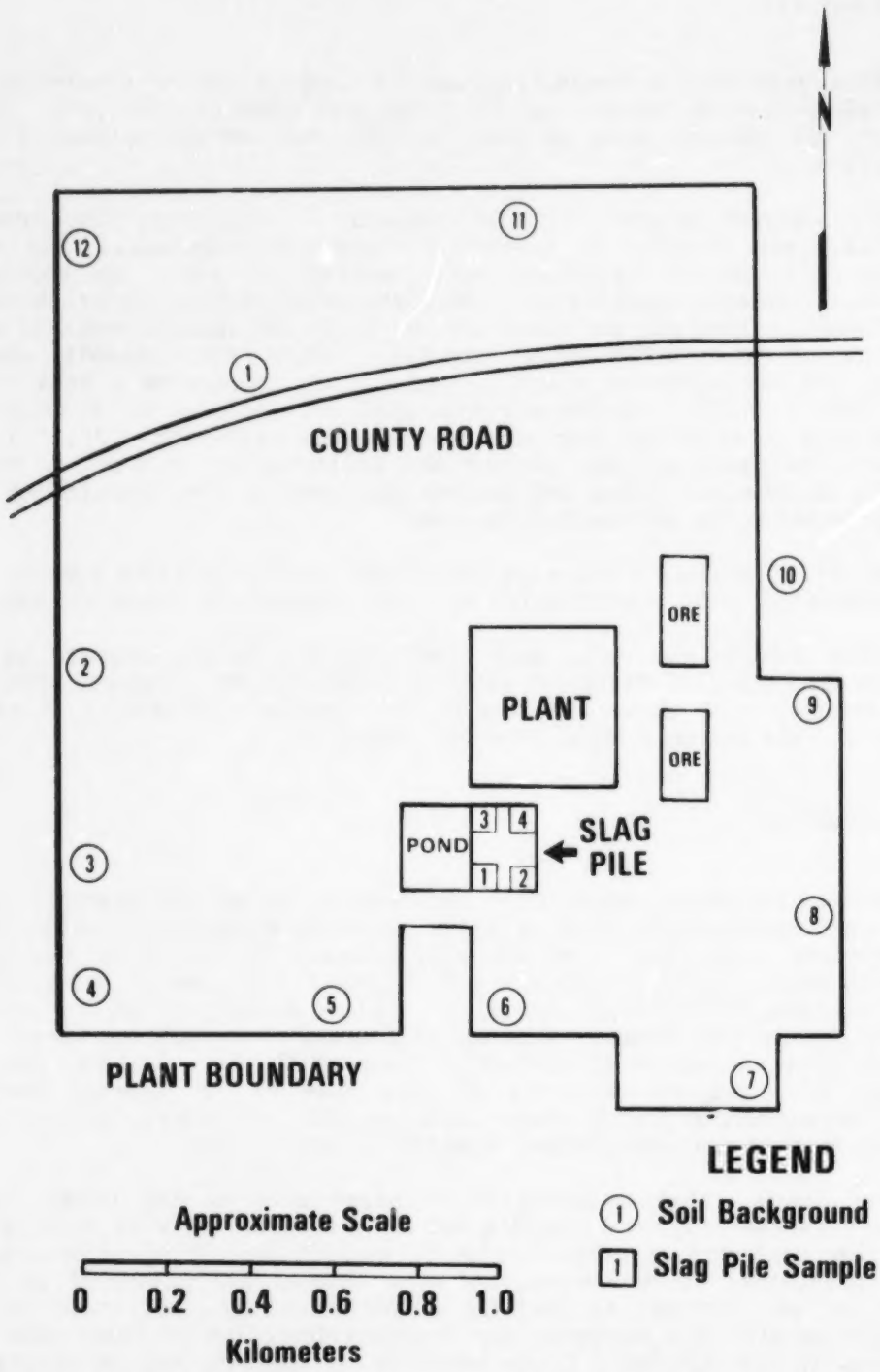

Figure 4. Sampling Sites for Radon Emanation from Soil, Ore, and Slag

SAMPLE ANALYSIS

PEDCo made mass determinations on TSP samples before forwarding them to Eberline Instrument Corporation (EIC) for radiochemical analysis. Stack and ambient gas samples were shipped to EIC for arrival within 2 days of collection.

EIC analyzed process and TSP samples by dissolving the samples and separating the elements of interest by chemical techniques. The separated uranium and thorium fractions were counted on alpha spectrometers for individual isotopic quantitation. An alpha scintillation counter measured the polonium-210. Lead was separated and set aside for about 2 weeks to allow for ingrowth of bismuth-210 from lead-210. After the ingrowth period the bismuth-210 was separated from the lead and was counted on a beta counter to quantitate lead-210. Radium was separated and enclosed as a solution in a sealed tube to allow for ingrowth of radon from radium-226. After 3 weeks of ingrowth the radon gas was evolved and collected in an alpha scintillation cell to be counted. Stack and ambient gas samples were transferred to alpha scintillation cells and counted for radon.

The EPA's project officer collected the slag pile radon samples directly into evacuated alpha scintillation cells and counted for radon the same day.

PEDCo shipped the radon emanation canisters by air express to the EPA Eastern Environmental Radiation Facility in Montgomery, Alabama. EPA analyzed the canisters on a gamma spectrometer and reported the results as radon flux (emission rate per unit area) from the surface.

DATA REPORTING

The radioactivity reported for each sample, except for charcoal canisters, is the net radioactivity plus or minus twice the standard deviation (2s) based on counting statistics. The net radioactivity is the gross sample radioactivity minus counter background and (1) for filter samples, minus an average value for the radioactivity content of a blank filter, or (2) for stack radon samples, minus the ambient radon concentration. The counting variation, plus the variable radioactivity content of individual blank filters, occasionally results in a net radioactivity of less than 0. Of course, there is no negative radioactivity. In these cases, as with all others, the net negative results must be considered along with the 2s uncertainty.

The sample standard deviation is based only on the random variations inherent in radioactivity counting and is propagated only in those situations of either duplicate emission samples or samples describing process materials. This uncertainty is not propagated when samples are collected at different times yet are combined to describe a source average. In these cases where multiple samples are averaged, the standard deviation is calculated from the variance in the samples. Since there is no adequate way of describing the variability in daily emissions for the control technology, the annual emissions have no associated error term.

SECTION 6

SAMPLE RESULTS

PROCESS SAMPLES

The average concentration in ore of radionuclides of the uranium-238 series was 32 pCi/g (Table 1). The apparent departures from secular equilibrium reported for the individual nuclides of the uranium series in ore samples are due primarily to a combination of statistical variations in counting and analytical biases. Uranium was above the normal concentration in rock by about a factor of 50. The thorium series was at a normal concentration level.

Although a large fraction of the ore was removed as elemental phosphorus and oxygen, the radionuclide concentrations in slag are similar to those in ore due to the diluting effect of the added silica. The major differences between ore and slag concentrations are for lead-210 and polonium-210, both of which are volatilized and driven off during processing. Radionuclide concentrations in the nodules show that about half the lead-210 and essentially all of the polonium-210 are lost during calcining. The rest of the lead-210 is lost during the thermal reduction process. FeP contains significant concentrations of uranium-234 and -238. However, the FeP is produced in much smaller quantity than slag and most of the uranium is found in the slag. Radionuclide concentrations in the four slag pile samples are in very close agreement, reflecting the uniformity of blended feedstock and overall operations.

AMBIENT AIR SAMPLES

Radon-222 concentrations measured at the background station are shown in Table 2. The samples collected from 1440 to 1758 hours on October 17 and on October 18 were collected during periods when the wind direction was primarily from the plant to the sampling site. All other samples were collected during periods when the sampling site was either upwind or crosswind from the plant. No effect of plant operation is apparent from the results and all samples are considered to represent ambient concentrations. Ambient radon concentrations vary from less than 0.1 to about 1 nCi/m^3, depending on time of day, season, and meteorology (1).

Three filters from the background high volume samplers were analyzed for ambient particulate radioactivity concentrations. The results are in Table 3. The measured concentrations of the uranium, thorium, lead, and radium isotopes are comparable to those found throughout the United States (1). The polonium-210 concentrations of 0.020 and 0.029 pCi/m^3 in the October 18-21 and October 26-28 samples are an order of magnitude higher than the normal back-

TABLE 1. PROCESS MATERIALS RADIOACTIVITY CONCENTRATIONS

Material	Radioactivity Concentrations (pCi/g)[a]							
	U-238	U-234	Th-230	Ra-226	Pb-210	Po-210	Th-232	Th-228
Phosphate Ore	29 ± 3	29 ± 3	54 ± 11	31 ± 9	41 ± 2	33 ± 3	0.20 ± 0.23	0.20 ± 0.23
Phosphate Ore	24 ± 2	23 ± 2	24 ± 6	21 ± 6	34 ± 2	38 ± 3	0.32 ± 0.30	0.84 ± 0.50
Average[b]	27 ± 2	26 ± 2	39 ± 6	26 ± 5	38 ± 1	36 ± 2	0.26 ± 0.19	0.52 ± 0.28
Nodules	26 ± 2	26 ± 2	51 ± 11	21 ± 6	22 ± 2	2.7 ± 3.9	0.06 ± 0.13	0.06 ± 0.13
Coke	0.24 ± 0.10	0.31 ± 0.12	0.31 ± 0.29	0.11 ± 0.03	0.52 ± 0.76	0.3 ± 2.8	0.06 ± 0.13	0.06 ± 0.13
Silica	0.14 ± 0.07	0.24 ± 0.09	0.48 ± 0.31	0.18 ± 0.05	0.55 ± 0.78	-0.3 ± 2.7	0.04 ± 0.09	0.04 ± 0.09
Fresh Slag	26 ± 2	26 ± 2	54 ± 13	31 ± 9	0.53 ± 0.90	0.0 ± 2.8	0.76 ± 0.47	0.43 ± 0.21
Fresh Slag	25 ± 4	25 ± 4	46 ± 14	28 ± 8	-1.4 ± 1.8	1.8 ± 3.1	1.1 ± 0.6	0.07 ± 0.14
Average[b]	26 ± 2	26 ± 2	50 ± 10	30 ± 6	-0.4 ± 1.0	0.9 ± 2.1	0.93 ± 0.38	0.25 ± 0.13
Ferrophosphorus	11 ± 3	7.6 ± 2.1	0.56 ± 0.44	0.35 ± 0.11	0.79 ± 0.88	-0.9 ± 2.5	0.08 ± 0.16	0.08 ± 0.16
Ferrophosphorus	10 ± 3	9.6 ± 3.1	0.45 ± 0.38	0.39 ± 0.12	0.67 ± 1.7	0.6 ± 2.9	0.07 ± 0.15	0.07 ± 0.15
Average[b]	11 ± 2	8.6 ± 1.9	0.51 ± 0.29	0.37 ± 0.08	0.73 ± 0.96	-0.2 ± 1.9	0.08 ± 0.11	0.08 ± 0.11
Slag, Drum Site 1	20 ± 2	20 ± 2	37 ± 8	24 ± 7	1.3 ± 0.9	6.8 ± 4.1	0.21 ± 0.21	0.21 ± 0.21
Slag, Drum Site 2	26 ± 2	26 ± 2	58 ± 18	29 ± 9	1.5 ± 0.8	1.1 ± 5.5	0.36 ± 0.28	0.95 ± 0.71
Slag, Drum Site 3	22 ± 2	22 ± 2	46 ± 18	21 ± 6	1.7 ± 1.3	1.4 ± 5.6	0.42 ± 0.28	0.73 ± 0.59
Slag, Drum Site 4	26 ± 2	26 ± 2	39 ± 8	34 ± 10	2.6 ± 1.3	0.32 ± 2.1	0.57 ± 0.33	0.58 ± 0.41
Average[b]	24 ± 1	24 ± 1	45 ± 7	27 ± 4	1.8 ± 0.6	2.7 ± 2.3	0.39 ± 0.14	0.62 ± 0.26

a Picocuries (10^{-12} curies) per gram plus or minus the standard deviation based on counting statistics.

b Counting statistic standard deviation propagated to average result.

ground of 0.001 to 0.003 pCi/m^3. The polonium-210 concentration of 0.0043 ± 0.0028 pCi/m^3 is in the range of expected background. Using the hourly average wind speed and direction data provided by Stauffer the estimated polonium-210 concentrations at the drive-in theater site were calculated. The estimates were made using a Gaussian plume diffusion model and Pasquill's diffusion categories (8). The calculated concentrations for the three sampling periods, including an estimated background of 0.001 pCi/m^3, were 0.027, 0.003, and 0.001 pCi/m^3. Of the first result, 0.021 pCi/m^3 was due to a 1-hour observation with an average wind speed of 0.8 km/h, and the background site was 1.6 km from the plant. If that 1-hour observation is not used in the calculations the predicted concentration becomes 0.006 pCi/m^3. From the calculations it is obvious that some polonium-210 above background would be expected at the drive-in theater site under the meteorological conditions observed on October 19-20 and 27-28. Considering the sensitivity of the predictive model to proper selection of stability factors and precise wind direction measurement, the measured values for polonium-210 concentration are believed to be valid.

TABLE 2. AMBIENT RADON-222 CONCENTRATIONS

Date	Time On - Off	Concentration (nCi/m^3)[a]
10/17	0910 - 1418	0.39 ± 0.10
10/17	1440 - 1758	0.16 ± 0.06
10/18	1032 - 1319	0.32 ± 0.09
10/18	1320 - 1635	0.20 ± 0.09
10/22	1058 - 1314	0.13 ± 0.06
10/22	1315 - 1605	0.12 ± 0.04[b]
10/22	1606 - 1859	0.17 ± 0.05

a Nanocuries (10^{-9} curies) per cubic meter plus or minus twice the standard deviation based on counting results only.

b Derived from duplicate samples.

TABLE 3. AMBIENT AND STACK PARTICULATE RADIOACTIVITY CONCENTRATIONS

Source	Time - Date Collected	Radioactivity Concentrations (pCi/m^3)[a]							
		U-238	U-234	Th-230	Ra-226	Pb-210	Po-210	Th-232	Th-228
Ambient Air	2355 - 10/18 0022 - 10/21	0.000049 ± 0.000076	0.00007 ± 0.00013	0.00008 ± 0.00035	-0.00013 ± 0.00045	0.020 ± 0.002	0.020 ± 0.002	0.00007 ± 0.00024	0.00008 ± 0.00018
Ambient Air	0026 - 10/26 0021 - 10/28	0.00016 ± 0.00010	0.00014 ± 0.00014	0.00037 ± 0.00039	0.00001 ± 0.00043	0.0074 ± 0.0023	0.029 ± 0.005	0.00009 ± 0.00025	0.00010 ± 0.00018
Ambient Air	0030 - 10/28 0049 - 10/30	0.00014 ± 0.00010	0.00013 ± 0.00014	0.00010 ± 0.00034	-0.00006 ± 0.00045	0.0074 ± 0.0014	0.0043 ± 0.0028	0.00008 ± 0.00025	0.00009 ± 0.00018
Kiln Feed Conveyor	0852 - 1032 10/30/79	-0.01 ± 0.22	0.12 ± 0.30	-0.02 ± 0.68	0.03 ± 0.42	0.7 ± 2.9	1.1 ± 1.4	-0.10 ± 0.44	-0.05 ± 0.42
Kiln Feed Conveyor	1305 - 1510 10/30/79	-0.01 ± 0.21	-0.02 ± 0.28	-0.03 ± 0.66	0.10 ± 0.42	0.3 ± 2.7	0.6 ± 1.3	-0.12 ± 0.42	-0.05 ± 0.40
Kiln 1 Scrubber Exhaust	1324 - 1627 10/25/79	0.34 ± 0.20	0.45 ± 0.26	0.26 ± 0.58	0.45 ± 0.34	380 ± 34	190 ± 27	-0.07 ± 0.33	-0.03 ± 0.32
Kiln 1 Scrubber Exhaust	1718 - 1943 10/25/79	0.32 ± 0.20	0.17 ± 0.24	0.42 ± 0.67	0.39 ± 0.34	420 ± 35	250 ± 28	-0.06 ± 0.35	-0.02 ± 0.34
Kiln 1 Scrubber Exhaust	1046 - 1701 10/26/79	0.19 ± 0.20	0.10 ± 0.25	-0.01 ± 0.15	0.40 ± 0.36	210 ± 7	290 ± 14	-0.07 ± 0.36	-0.03 ± 0.35
Nodule Cooler	0940 - 1610 10/19/79	0.36 ± 0.26	0.28 ± 0.31	0.4 ± 1.2	0.63 ± 0.45	0.3 ± 2.8	11 ± 3	-0.08 ± 0.45	-0.03 ± 0.43
Nodule Cooler	0941 - 1612[b] 10/19/79	0.05 ± 0.18	0.05 ± 0.24	0.08 ± 0.56	0.06 ± 0.33	0.1 ± 2.2	7.4 ± 1.8	0.02 ± 0.39	0.06 ± 0.38
Nodule Cooler	0956 - 1225[b] 10/24/79	-0.07 ± 0.18	-0.07 ± 0.24	-0.02 ± 0.55	0.20 ± 0.35	0.7 ± 2.4	0.8 ± 1.1	-0.08 ± 0.36	-0.04 ± 0.34

(continued)

TABLE 3. (Continued)

Source	Time - Date Collected	Radioactivity Concentrations (pCi/m^3)[a]							
		U-238	U-234	Th-230	Ra-226	Pb-210	Po-210	Th-232	Th-228
Kiln Building Ventilator	1305 - 1553 10/19/70	0.37 ± 0.29	0.37 ± 0.32	0.51 ± 0.77	0.57 ± 0.37	1.3 ± 2.2	0.19 ± 0.94	-0.02 ± 0.34	0.01 ± 0.33
Kiln Building Ventilator	0955 - 1225 10/24/79	0.36 ± 0.32	0.51 ± 0.41	1.3 ± 1.1	0.77 ± 0.51	0.02 ± 3.2	-0.4 ± 1.4	-0.11 ± 0.49	0.06 ± 0.47
Kiln Building Ventilator	1000 - 1224 10/24/79	0.29 ± 0.20	0.29 ± 0.23	0.29 ± 0.44	0.42 ± 0.29	0.5 ± 1.7	-0.14 ± 0.69	-0.06 ± 0.25	-0.03 ± 0.24
Silo System Exhaust	1015 - 1221 10/29/79	0.23 ± 0.21	0.32 ± 0.26	0.39 ± 0.58	0.77 ± 0.39	1.2 ± 2.0	0 ± 1.5	0.05 ± 0.35	0.08 ± 0.34
Silo System Exhaust	1421 - 1624 10/29/79	-0.06 ± 0.14	-0.06 ± 0.18	-0.03 ± 0.43	-0.11 ± 0.26	0.7 ± 1.8	0 ± 1.2	-0.08 ± 0.26	-0.05 ± 0.25
Tap Hole Fume Scrubber	1550 - 1805 10/16/79	0.01 ± 0.14	0.04 ± 0.18	-0.01 ± 0.41	-0.10 ± 0.25	0.6 ± 1.7	0 ± 0.75	-0.06 ± 0.26	-0.03 ± 0.25
Tap Hole Fume Scrubber	0935 - 1145 10/17/79	-0.04 ± 0.14	-0.06 ± 0.18	-0.02 ± 0.41	-0.04 ± 0.25	7.9 ± 1.1	15 ± 5.4	-0.07 ± 0.26	-0.04 ± 0.25
Tap Hole Fume Scrubber	1435 - 1637 10/17/79	-0.01 ± 0.14	-0.01 ± 0.18	-0.02 ± 0.43	-0.18 ± 0.26	4.2 ± 0.8	3.1 ± 3.9	-0.06 ± 0.27	-0.03 ± 0.26

[a] Picocuries (10^{-12} curies) per cubic meter plus or minus twice the standard deviation based on counting results only.

[b] Results derived from duplicate samples.

EMISSION SAMPLES

Radon sampling results are shown in Table 4. Gross concentrations measured in the stacks, net concentrations above the measured ambient concentrations and average concentrations are given along with the derived annual emission rates. Annual emission rates were calculated assuming full-time operation of the process and annual average concentrations equal to the average obtained from the samples.

Two sources, the kilns and the silo system exhaust, had average concentrations which were significantly different from ambient. Net average radon concentrations were 12 ± 11 and 0.12 ± 0.17 nCi/m^3 respectively. The associated annual releases were 8.2 and 0.034 curies. Thus, the kilns were responsible for essentially all the radon emitted from the plant stacks.

Particulate radioactivity concentrations measured in stack emissions are given in Table 3. These concentrations are calculated using the radionuclide activity on the filter media and the sample volume corrected to stack conditions. Using these values, the stack emission rates (pCi/sec) were determined and summarized in Table 5. These rates are calculated from the ratio of the stack flow rate (in standard ft^3/hr, dry) to the sample volume (standard ft^3, dry). Specific stack test and sample parameters are contained in the emission test report (5). PEDCo Environmental has calculated and summarized these ratios or "scaling factors."

Radioanalytical results for the kiln feed conveyor exhaust samples were not significantly different from zero. PEDCo reported an average mass emission rate from this source of 0.98 pounds per hour (0.12 g/sec). Using the measured radioactivity in ore, each of the uranium chain radionuclides should have been emitted at the rate of 4 pCi/sec from the kiln feed conveyor exhaust.

The emission rates of uranium-238 and -234, thorium-230, and radium-226 in the kiln scrubber exhaust averaged about 3.6 pCi/sec. Emission rates of lead-210 and polonium-210 from the kiln scrubber exhaust were 4,500 pCi/sec and 3,200 pCi/sec, respectively.

Measured concentrations and emission rates of uranium-238 and -234, thorium-230, radium-226, and lead-210 from the nodule cooler did not differ significantly from zero. Based on the measured mass emission rates and radioactivity of the nodules the best estimate of the release rates of each of those radionuclides would be 2.7 pCi/sec. Only polonium-210 was measured at concentrations significantly above zero. The average emission rate was 50 pCi/sec.

The kiln building ventilator is the major controlled source of particulates. As a consequence it was also the major source of uranium-238 and -234, thorium-230, and radium-226. Emissions of each of those radionuclides plus lead-210 averaged 15 pCi/sec.

TABLE 4. RADON-222 STACK EMISSIONS

Source	Time	Date	Concentration (nCi/m^3)[a] Gross[b]	Concentration (nCi/m^3)[a] Net[c]	Annual Release (Ci)
Kiln Feed Conveyor	1106 - 1320	10/18	0.36 ± 0.13	0.04 ± 0.16	
	1320 - 1623	10/18	0.23 ± 0.11	0.03 ± 0.14	
	1041 - 1309	10/22[d]	0.22 ± 0.04	0.09 ± 0.07	
		Source Average		0.05 ± 0.03	0.013
Kiln	0930 - 1328	10/18	14 ± 1	14 ± 1	
	1328 - 1555	10/18	0.35 ± 0.14	0.15 ± 0.15	
	1025 - 1358	10/22[d]	22 ± 1	22 ± 1	
		Source Average		12 ± 11	4.1
		Total for 2 kilns			8.2
Nodule Cooler	1005 - 1420	10/18	0.33 ± 0.09	0.01 ± 0.13	
	1627 - 1829	10/22[d]	0.30 ± 0.05	0.13 ± 0.07	
		Source Average		0.07 ± 0.08	0.020
		Total for 2 coolers			0.040
Kiln Building Ventilator	1153 - 1345	10/18	0.45 ± 0.13	0.13 ± 0.16	
	1623 - 1823	10/22[d]	0.16 ± 0.04	-0.01 ± 0.07	
		Source Average		0.06 ± 0.10	0.047
		Total for 2 ventilators			0.094
Silo System Exhaust	1400 - 1643	10/22	0.12 ± 0.09	0.00 ± 0.10	
	1646 - 1846	10/22	0.41 ± 0.04	0.24 ± 0.06	
		Source Average		0.12 ± 0.17	0.034
Tap Hole Fume Scrubber	0933 - 1410	10/17	0.28 ± 0.10	-0.11 ± 0.14	
	1413 - 1740	10/17	0.23 ± 0.08	0.07 ± 0.10	
		Source Average		-0.02 ± 0.13	-0.010

a Nanocuries (10^{-9} curies) per cubic meter.
b Radon-222 concentration in sample as collected plus or minus twice the standard deviation based on counting statistics.
c Radon-222 concentration in sampling minus the concentration in ambient air during the sample collection period. Source averages are the mean of the samples plus or minus the standard deviation based on sample variance about the mean.
d Results derived from duplicate samples.

TABLE 5. PARTICULATE RADIOACTIVITY EMISSION RATES

Source	Time - Date Collected	Radioactivity Emission Rates (pCi/sec)[a] U-238	U-234	Th-230	Ra-226	Pb-210	Po-210	Th-232	Th-228
Kiln Feed Conveyor	0852 - 1032 10/30/79	-0.13	1.2 ± 3.0	-0.22 ± 6.7	0.27 ± 4.2	7.2 ± 28	11 ± 13	-0.93 ± 4.3	-0.45 ± 4.2
Kiln Feed Conveyor	1305 - 1510 10/30/79	-0.9	-0.22 ± 2.8	-0.30 ± 6.5	1.0 ± 4.2	2.7 ± 27	5.7 ± 13	-1.2 ± 4.2	-0.52 ± 4.0
	Average	-0.11 ± 1.6	0.5 ± 2.1	-0.26 ± 4.7	0.64 ± 3.0	5.0 ± 19	8.4 ± 9.2	-1.1 ± 3.0	-0.49 ± 2.9
Kiln 1, Scrubber Exhaust	1324 - 1627 10/25/79	4.6 ± 2.7	6.0 ± 3.5	3.5 ± 7.8	6.0 ± 4.7	5000 ± 470	2500 ± 14	-0.97 ± 4.5	-0.47 ± 4.3
Kiln 1, Scrubber Exhaust	1718 - 1943 10/25/79	4.3 ± 2.7	2.3 ± 3.3	5.7 ± 9.0	5.2 ± 4.7	5800 ± 480	3300 ± 380	-0.80 ± 4.8	-0.28 ± 4.7
Kiln 1, Scrubber Exhaust	1046 - 1701 10/26/79	2.5 ± 2.6	1.3 ± 3.2	-0.13 ± 1.8	5.2 ± 4.5	2700 ± 100	3800 ± 180	-0.88 ± 4.7	-0.37 ± 4.5
	Average	3.8 ± 1.5	3.2 ± 1.9	1.9 ± 4.0	5.5 ± 2.7	4500 ± 230	3200 ± 140	-0.88 ± 2.7	-0.37 ± 2.6
Nodule Cooler	0940 - 1610[b] 10/19/79	1.9 ± 1.5	1.0 ± 1.8	2.0 ± 5.8	3.0 ± 2.6	1.9 ± 17	85 ± 16	-0.24 ± 2.8	0.45 ± 2.7
Nodule Cooler	0956 - 1225 10/24/79	-1.3 ± 3.2	-1.3 ± 4.3	-0.33 ± 9.9	3.6 ± 6.2	13 ± 43	14 ± 20	-1.4 ± 6.4	-0.66 ± 6.1
	Source Average	0.30 ± 1.9	-0.15 ± 2.3	0.84 ± 5.7	3.3 ± 3.4	7.5 ± 23	50 ± 13	-0.82 ± 3.5	-0.11 ± 3.3
Kiln Building Ventilator	1305 - 1553 10/19/79	7.6 ± 5.9	7.6 ± 6.6	10 ± 16	12 ± 7.6	27 ± 44	4.0 ± 19	-0.48 ± 7.0	0.28 ± 6.7
Kiln Building Ventilator	0955 - 1225[b] 10/24/79	12 ± 6.6	15 ± 8.6	28 ± 21	21 ± 11	9.0 ± 63	-9.0 ± 28	-3.1 ± 9.7	0.45 ± 9.6
	Source Average	9.8 ± 4.5	11 ± 5.4	19 ± 14	17 ± 6.7	18 ± 38	-2.5 ± 17	-1.8 ± 6.0	0.37 ± 5.9
Silo System Exhaust	1015 - 1221 10/29/79	2.5 ± 2.2	3.4 ± 2.8	4.1 ± 6.1	8.2 ± 4.1	12 ± 22	0 ± 16	0.51 ± 3.7	0.88 ± 3.6
Silo System Exhaust	1421 - 1624 10/29/79	-0.72 ± 1.7	-0.72 ± 2.2	0.41 ± 5.1	1.3 ± 3.2	7.9 ± 22	0 ± 14	-0.96 ± 3.2	-0.58 ± 3.0
	Average	0.89 ± 1.4	1.3 ± 1.8	2.3 ± 4.0	4.8 ± 2.6	10 ± 16	0 ± 11	-0.23 ± 2.4	-0.15 ± 2.3
Tap Hole Fume Scrubber	1550 - 1805 10/16/79	0.2 ± 2.6	0.70 ± 3.4	0.25 ± 7.7	1.9 ± 4.6	12 ± 32	0 ± 14	-1.1 ± 4.9	-0.5 ± 4.7
Tap Hole Fume Scrubber	0935 - 1145 10/17/79	-0.83 ± 2.6	-1.1 ± 3.4	-0.42 ± 7.9	-0.73 ± 4.8	150 ± 21	290 ± 100	-1.2 ± 5.0	-0.69 ± 4.9
Tap Hole Fume Scrubber	1435 - 1637 10/17/79	-0.15 ± 2.5	-0.15 ± 3.3	-0.35 ± 7.7	-3.3 ± 4.7	75 ± 15	55 ± 70	-1.2 ± 4.9	-0.61 ± 4.7
Time-Weighted Average[c]						43 ± 13	85 ± 33		

a Picocuries (10^{-12} curies) per cubic meter.
b Results derived from duplicate sample
c Emission rates of nuclides other than Pb-210 and Po-210 were insignificant.

The average emission rates of the uranium chain radionuclides, less polonium-210, from the silo system exhaust was measured at 3.8 pCi/sec. Assuming that the particulate material sampled was due to nodule handling and that the radioactivity concentration of the particulates was the same as the nodules, the average emission rate of each, based on the mass emission rate, would be 3.1 pCi/sec, very close to the measured radioactivity emission rate.

The collection period of each tap hole fume scrubber sample included times when a furnace was being flushed or tapped. Analysis of the data showed that the primary source of lead-210 and polonium-210 from the source was FeP tapping. As shown in Table 3, the concentrations of other radionuclides did not differ significantly from zero and lead-210 and polonium-210 concentrations varied widely between samples. The time-weighted average emission rates based on 2-days tap and flush records and the three sample results were 43 pCi/sec for lead-210 and 85 pCi/sec for polonium-210.

Table 6 shows the annual emission rates calculated for each operation. These emission rates include the sum of two kiln stacks, two nodule cooler stacks, and two kiln building ventilator stacks. Approximately 99 percent of the lead-210 and 97 percent of polonium-210 emissions occur from the kiln stacks. The process sample results show that essentially all of the lead-210 and polonium-210 is driven off in the kiln and furnace. The observed difference in kiln annual emissions of 280 mCi and 200 mCi, may be real, due to different removal rates in pollution control equipment, or may be an artifact of analysis. The kilns also emit several tenths of a curie per year of the other uranium chain radionuclides, but most of them - about 1 Ci per year - are released from the kiln building ventillator systems.

The removal of radionuclides by emission control systems was determined on the number 1 kiln scrubber and the tap hole fume scrubber. As is common with kilns, Stauffer uses an effluent control system of multiple control devices in series. It was possible to obtain simultaneous samples on the inlet and outlet of the final stage scrubber. Simultaneous samples were also obtained at the inlet and outlet of the tap hole fume scrubber. The results are shown in Table 7. The kiln scrubber removed 75 percent of the total mass entering it. The average removal for uranium, thorium, and radium was essentially identical at 78 percent. Both lead-210 and polonium-210 showed a 54 percent removal. Only lead-210 and polonium-210 could be evaluated in the tap hole fume scrubber. The fume scrubber removed an average of 86 percent of those nuclides, compared to 91 percent of the mass. Lead and polonium, presumed to be present as fumes after condensing from vapors, are apparently more readily removed in the tap hole fume scrubber than in the kiln scrubber which is designed to remove particulates.

RADON EMANATION RESULTS

Radon emanation rates from soil around the plant generally ranged from 12 to 31 pCi/m^2-min with an average of 21 ± 6 (Table 8). If two low results of 2.0 and 4.2 pCi/m^2-min are included the average is 18 ± 9. Radon emanation from the top of the ore pile covered with roaster residue average 53 ± 35 pCi/m^2-min. Considerable difference was found between the emanation rates

TABLE 6. PARTICULATE RADIOACTIVITY ANNUAL EMISSION RATES

Source	Annual Emission Rate (mCi/y)[a]							
	U-238	U-234	Th-230	Ra-226	Pb-210	Po-210	Th-232	Th-228
Kiln Feed Conveyor	-0.003 ± 0.050	0.016 ± 0.066	-0.008 ± 0.15	0.020 ± 0.095	0.16 ± 0.60	0.26 ± 0.29	0.035 ± 0.095	-0.015 ± 0.091
Kiln 1 plus Kiln 2	0.24 ± 0.09	0.20 ± 0.12	0.12 ± 0.25	0.35 ± 0.17	280 ± 15	200 ± 7	-0.06 ± 0.17	-0.02 ± 0.16
Nodule Cooler 1 plus Nodule Cooler 2	0.02 ± 0.11	-0.009 ± 0.15	0.05 ± 0.36	0.21 ± 0.21	0.47 ± 1.5	3.2 ± 0.8	-0.05 ± 0.22	0.007 ± 0.21
Kiln Building Ventilator	0.62 ± 0.28	0.70 ± 0.34	1.2 ± 0.9	1.1 ± 0.4	1.1 ± 2.4	-0.16 ± 1.1	-0.12 ± 0.38	0.02 ± 0.36
Silo System Exhaust	0.028 ± 0.044	0.041 ± 0.057	0.07 ± 0.13	0.15 ± 0.08	0.32 ± 0.50	0 ± 0.35	-0.007 ± 0.076	-0.005 ± 0.073
Tap Hole Fume Scrubber[b]					1.4 ± 0.4	2.7 ± 1.0		

[a] Millicuries (10^{-3} curies) per year plus or minus twice the standard deviation based on counting results only.

[b] Emissions of nuclides other than Pb-210 and Po-210 were insignificant and time-weighted averages were not determined.

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measured from the east berm of the ore pile and the west berm. The three measurements from the east berm averaged 310 ± 140 pCi/m^2-min while those from the west berm averaged 36 ± 20 pCi/m^2-min. No explanation has been found to explain the difference between the two berms. The average radon emanation rate from the ore pile was 110 ± 70 pCi/m^2-min. The radon emanation rate from the ore pile in use should have been about equal to the berm average, or 170 ± 140 pCi/m^2-min. Radon emanation rates measured on the slag pile averaged 3.5 ± 3.7 pCi/m^2-min.

Radon emanation rates from soil were comparable to those measured at other locations in the United States as part of this survey, but were below the reported National average value of 35 pCi/m^2-min (9).

It is estimated that the covered ore pile emits radon at the rate of 1.2 ± 0.8 µCi/min. The uncovered ore pile is estimated to release radon at the rate of 1.9 ± 1.5 µCi/min. The radon which would have been released from the soil beneath the ore piles was about 0.2 µCi/min. The net radon emanation rate for the two piles would be 1.0 ± 0.8 µCi/min or 0.53 Ci/year for the covered pile and 1.7 ± 1.5 µCi/min or 0.89 Ci/year for the pile in use.

Radon emanated from the slag pile at the rate of 0.8 µCi/min compared to an emission rate from the soil beneath of 0.4 µCi/min. The radon reduction provided by the slag cover is estimated to be 0.32 µCi/min or 0.17 Ci/year.

The net radon emanation rate from the ore and slag piles during the survey was estimated at 1.2 Ci/year. However, during part of the year only a portion of one ore pile would be in existence and snow and ice cover during the winter would reduce the radon emanation rate.

TABLE 7. SCRUBBER REMOVAL OF RADIONUCLIDES

	Fraction Removed (Percent)								
Location	U-238	U-234	Th-230	Ra-226	U,Th,Ra Average	Pb-210	Po-210	Pb,Po Average	Mass
Kiln 1	71	59	76	59	66	37	58	48	75
Kiln 1	85	93	85	81	86	68	66	67	74
Kiln 1	69	87	100	69	81	57	38	48	76
Average	75	80	87	70	78	54	54	54	75
Tape Hole Fume Scrubber						95	100	98	100
Tape Hole Fume Scrubber						73	75	74	81
Average						84	88	86	91

TABLE 8. RADON-222 EMANATION RATES FROM SOIL, ORE, AND SLAG

Soil		Ore Pile		Slag Pile	
Site	Emanation Rate (pCi/m^2-min	Site	Emanation Rate (pCi/m^2-min	Site	Emanation Rate (pCi/m^2-min)
1	18	Top			
2	17	1	75	1	1.8
3	22	2	100	2	8.6
4	18	3	22	3	3.3
5	4.2	4	30	4	0.1
6	12	5	35	Average	3.5 ± 3.7
7	24	Average	53 ± 34		
8	28				
9	13	East Berm			
10	25	6	150		
11	2.0	7	390		
12	31	8	380		
Average	18 ± 9	Average	310 ± 140		
		West Berm			
		9	13		
		10	48		
		11	47		
		Average	36 ± 20		

SECTION 7

POPULATION DISTRIBUTION

The Stauffer Chemical Company plant is located in a sparsely populated area. The processing facility is situated, as shown in Figure 4, near the east center portion of a company-owned site about 1 mile (1.6 km) square which is fenced to restrict access. Several ranches are located west of the plant, with the nearest residence in that direction being about 2 km away. One family lives at the drive-in theater 1.6 km east of the plant. Several residences are occupied in Silver Bow about 2.5 km northeast and about 50 people live in Ramsey, about the same distance to the north-northwest.

SECTION 8

DISCUSSION OF RESULTS

As mentioned earlier, analytical biases can result in consistent differences in activity levels between radionuclides of a decay chain that would normally have very nearly the same radioactivity. This can be seen in the process sample results of Table 1 and kiln building ventilator results in Tables 3, 5, and 6. Radionuclides of the uranium decay chain through radium-226 in ore, modules, and slag and probably in ventilator exhaust particulates should be at nearly equilbrium values.

Other results reported by EIC on known activity samples have shown similar biases with thorium-230 being about twice the activity of the other samples. Evaluation of those results has shown that thorium analyses by EIC have been more accurate than the others. Therefore, it is believed that the thorium-230 results reported for the samples mentioned are more representative of the uranium chain activities than the other radionuclides. However, no attempt has been made in this report to apply any correction to the data. More important than the specific radioactivities are the fractions of the radioactivity in the process which are emitted from the stack. Since the biases are probably consistent, the fractional values are considered to be valid.

A major environmental protection problem associated with thermal processing of phosphate is the emission of fluorides to the atmosphere. To combat that problem and control particulate emissions Stauffer uses multiple air cleaning systems in series on its kilns, nodule coolers, and kiln building ventilators. Although radioactive emissions were not a consideration when the pollution control system was installed, it removed large fractions of the particulate radionuclides and smaller, but still significant, fractions of the more volatile lead-210 and polonium-210.

Each exhaust stack emits a portion of the particulate material controlled by the exhaust system. Due to the above-average concentrations of naturally-occurring radioactivity in the process materials the particulate emissions result in radioactive emissions. Most of the radioactive particulate emissions from controlled sources come from the kiln building ventilator. Next in importance is the kiln. The kiln probably generates more airborne particulates, but because of the more complex pollution control system actually emits less than the ventilator.

The average measured emissions of uranium-234 and -238, thorium-230, and radium-226 from all controlled sources were 1.3 mCi/year. A better estimate is probably derived from the measured mass emission rates. Assuming that the particulate material, except for the tap hole fumes, are similar to ore in radionuclide concentration the calculated total emissions of each of the four radionuclides is 4.2 mCi/year.

The nodule cooler and tap hole fume scrubber are small sources of lead-210 and polonium-210. The kilns, however, are the major source, releasing 99 and 97 percent, respectively, of the total plant emissions of those nuclides.

As with lead-210 and polonium-210, the kilns are the major source of radon emissions. The average measured emission rate of 8.2 Ci/year may be low since it is based on results from four samples, one of which was extremely low. The estimate of 1.5 Ci/year of radon from the ore pile is probably an upper limit, considering the actual area of the ore piles averaged over the year and the effect of winter rain, snow, and ice on reducing emanation rates.

Comparison of radioactivity removed by the kiln scrubber and tap hole fume scrubber demonstrated that the fume scrubber removed the larger fraction of the lead-210 and polonium-210 from the exhaust gases. Within the limits of sampling and analytical accuracy, the kiln scrubber removes the other, nonvolatile radionuclides in the same proportion as total suspended particulates. As would be expected for a noble gas, no removal of radon was exhibited by the kiln scrubber.

Although slag was found to contain about as much radium-226 as the original ore it was found to not be a source of radon, as is the ore. The physical form of the slag, even when somewhat frothy in appearance reduces the rate at which radon gas is able to escape. Slag pile sites sampled included slag which has been in place for a few days to several weeks so that at some sites the radon would have been in equilibrium with radium-226. Gamma exposure rates were significant on the slag pile, averaging 0.15 milliroentgen per hour (mR/h). Ambient background gamma exposure rates were about 0.01 mR/h.

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